

From Robotic and Virtual Soccer to Space Exploration Missions


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Robotic space exploration is a challenging and difficult task requiring high levels of adaptive ability on the part of the robots, at both software and hardware levels. Autonomous explorers must face extremely harsh environmental conditions, which severely affect the performance of the hardware, and greatly increase the demands placed on the controlling software. These are exacerbated by operation in a multi-agent operation, in which multiple agents are to also coordinate their behavior. In particular, the software must compensate for the changing conditions in the environment and in other agents, by adapting the agent's computational faculties to work reliably and optimally in any set of conditions, and with varying relationships with other agents.

This requirement for highly adaptive capabilities mandates the development of physical and software agents which can autonomously monitor their external and internal environments, and respond to changing conditions, at both individual and group levels. However, techniques which work well in one environment are often less-than-useful in another. Particular environmental parameters give rise to particular agent design characteristics which allow the agent to perform well in the context of these parameters, but not of others. The lack of a standard domain makes cross-validation and comparison of techniques difficult, as different researchers have access to different domains. The end result is that most often, researchers have no way to seriously evaluate the domain-independence features of their work.

The Robot World Cup Initiative (RoboCup) is an attempt to foster research in AI, Robotics and related fields by providing a standard problem where a critical technologies must all be integrated and examined. The main domain chosen for this task is based on soccer. This domain provides many opportunities for research into multi-agent systems involving competition and collaboration, teamwork, agent and team modeling, on- and off-line learning, etc. by both synthetic agents (in Soccer simulations) and robots. Inspired by the Apollo mission, RoboCup is intended to be a landmark project: The main benefits from RoboCup are expected to be in general fields of Computer Science, Electrical and Mechanical Engineering, etc., not in a soccer-playing agent. The RoboCup Federation is thus a-priori seeking to foster research of general, domain-independent techniques, and is strongly emphasizing and encouraging evaluation of the research in the context of multiple domains with varying characteristics. In particular, the RoboCup Federation is actively looking for additional domains besides soccer, such as space exploration, search-and-rescue operations, and unmanned vehicles, in which researchers may be able to work and evaluate domain-independent techniques.

The Information Sciences Institute at the University of Southern California is home to the two largest RoboCup research groups in the U.S.: The middle-size robots' *DreamTeam*, and the synthetic agents' *ISIS*. Over the past two years the two groups have conducted research in the context of these two RoboCup domains, ranging from vision and integration through on-line and off-line learning and adaptation, to general domain-independent teamwork and plan-execution monitoring. The purpose of this talk will be to present the RoboCup domain to robotic space-exploration researchers, and examine the mutual challenges and common interests of the two fields of research in aiming for general adaptive capacity in robotic and synthetic multi-agent systems. In particular, we will present the lessons learned from two years of research in robotic and synthetic soccer as they pertain to agent design, collaboration, learning, and robustness.



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The RoboCup Initiative


- Int'l scientific initiative -- promote AI, robotics
- Provide standard domains, landmark challenge
 - Inspired by the Apollo landmark project example
 - Emphasis on domain-independent techniques
 - Humanoid robots play soccer against humans
- AI/Robotics challenges:
 - Robust integration of hardware and software
 - Real time, adaptive control in dynamic settings
 - Collaboration (Teamwork) and Coordination
- Currently, simulation and wheeled soccer
 - Annual competitions and workshops
 - 1500 people, 22 countries



Abstract View of Bio-mimetic Agents

Common themes of biological systems:

- Integration and synergy of components
 - Everything fits together so nicely!
- Robustness and Autonomy
 - Biological systems handle novel situations
 - No tele-operation
- Simplicity and efficiency
 - Simple, efficient, real-time solutions
- Social Behavior
 - Coordination, Collaboration



RoboCup at USC/ISI

Virtual Soccer Team: ISIS Synthetic Agents

- Domain-independent teamwork and coordination
- Fault-tolerance, robustness
- Learning and adaptation

Mid-Sized Robot Team: USC/ISI DreamTeam

- Total autonomy: everything on-board
- Simple design for integrated, robust behavior
- Coordination through role assignment
- Adaptation

Team ISIS:

■ ISIS At a glance

- Strong research emphasis
- 1997: World 3rd place, top U.S., 1998: World 4th place

■ Teamwork and coordination

- "Bio-mimetic social relations"
- **What are the principles of working together?**

■ Robustness, behavior monitoring

- "Bio-mimetic fault-tolerance"
- **What are the principles of working correctly, reliably?**

■ Learning and Adaptation

- "Bio-mimetic adaptability"
- **What are the principles of adaptation and learning?**

Domain-Independent Teamwork/Collaboration: STEAM

Key Idea: Provide agents with knowledge of **teamwork**

- Outlines team members' responsibilities, benefits
- Contrasts with just relying on domain-specific coordination
- Builds on teamwork theories: SharedPlans, Joint Intentions

Advantages:

- Robustness in the presence of unanticipated events
- Reuse/transfer to other domains (tested in 4 so far)

Challenges:

- Flexible coordination, communication, team organization
- Collaborative negotiation
- Team plan execution, monitoring, recovery
- Collaborative learning and training

Example of STEAM in Action (Soccer)

STEAM Handles communication (content, timing):

■ Establishment

- When one of three defenders sees ball, alerts others and jointly establish team-level goal

■ Application

- defenders try to clear ball (individual sub-goal)

■ Termination

- If ball kicked away, defenders alert each other

Learning and Adaptation

Offline Learning

- Learning skills that are difficult to program manually
- e.g., Learning which direction to kick towards goal
 - Considers opponents position, distance, etc.
 - Implementation: C4.5

Online Learning/Adaptation

- Adapting at run-time to changing conditions
- e.g., Learning which ball-interception plans work
 - Considers frequency of sensor readings, actions
 - Implementation: Reinforcement learning



Fault-Tolerance & Recovery (Robustness)

- Failures *will occur* in many complex systems
- Situation worse for Multi-Agent Systems:
 - Now have to deal with other's failures, comm. failures
- Teamwork model is preventive and reactive
 - Attempts to make sure agents are coordinated
 - Has re-planning capabilities to handle some failures
- Social settings can be utilized for robustness
 - Can detect when others fail
 - Can use others for information on correct behavior
 - Social diagnosis: (Kaminka and Tambe, AAAI-98)

(In Battlefield Simulation Domain)

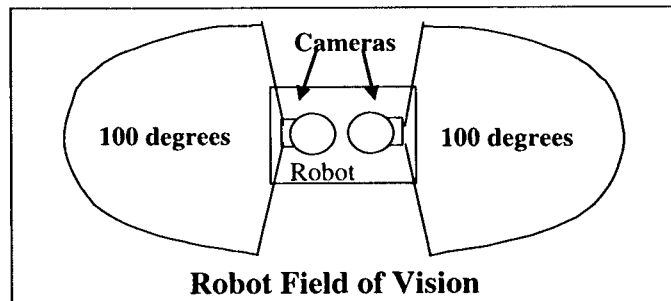


USC/ISI DreamTeam: Integrated Robots

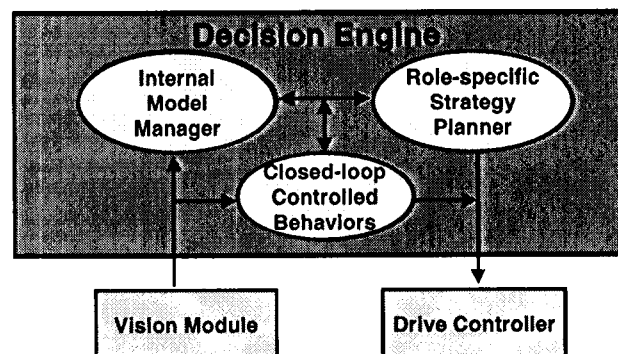
- Autonomous: Everything on Board
 - Sensing, thinking, and acting
- Efficient
 - Function under time and resource constraints
- Intelligent
 - Reasoning, planning, and potential learning
- Collaborative
 - Accomplish more than individual capability

Hardware Design

- Body: Modified toy truck
- Brain: All-in-one 586 system
- Eye: 2 QuickCam on parallel ports




Software Design





Collaboration

- Coordination by role assignment
- No explicit collaboration (passing) yet
- Emerged team behaviors
 - e.g., two forwards help each other
- Interference
 - can be avoided if recognize teammates



DreamTeam: Summary

- At the present, an effective way to build integrated robots:
 - use the least sophistication to achieve the most robustness
- A new set of issues to be addressed
 - team learning (not single agent learning)
 - new program semantics

Conclusions:

■ There exist general principles of:

- Coordination and collaboration
- Robustness and fault tolerance
- Integration
- Adaptation

■ In order to find them:

- Must work with different domains
- RoboCup Soccer is **one** excellent domain
 - (*ISIS also worked with others*)
- More needed -- RoboCup Space Explorers?

Once discovered, extremely useful!